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Oil Refinery Energy Optimization: Alkylation Unit

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Possible method for determining the energy efficiency will be presented taking one refinery unit named alkylation unit as an example. From the aspect of energy, the efficiency and optimization of alkylation unit is analyzed through the cost price of high, medium, and low pressure steam and the possible money savings that can be realized by eliminating differences between the target standard (average energy consumption standards of Western European refineries) and specific energy consumption.
High pressure steam consumption is 80000 t/y or 258 TJ. The consumption of medium pressure steam is 140000 t/y or 419 TJ. Own generation of low pressure steam, obtained by reduction on back-pressure turbines, is 20000 t/y or 55 TJ and is used for own consumption. Price of high pressure steam, supplied from Refinery Power Plant, is 10.83 US$/t, price of medium pressure steam, supplied from Refinery Power Plant too, is 9.66 US$/t, and price of low pressure steam, generated on the alkylation unit, is 11.78 US$/t.
Concerning the possibilities of monitoring and increasing of energy efficiency and optimization, through net consumption target standard, and specific gross and net energy consumption of outlined unit, upon analysis it can be shown that inefficiency index is 193%. Possible money savings realized by eliminating these differences are approximately 1.14 million US$ per annum. Money saving can be realized by using more efficient technological, energy and organizational solutions. In this paper we are presenting possible method for determining the energy efficiency.

Key words: *alkylation unit, technological/energy characteristics, energy optimization, money saving, target standard*

Technological characteristics of the alkylation unit

In alkylation of iso-butane with olefins, the hydrocarbon isomers in the boiling range of gasoline are obtained in the presence of sulphuric acid as a catalyst. Reaction oc-

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curs in the liquid phase when olefins come into contact with acid and large excess of iso-butane, the bigger portion of which has an impact on improvement of alkylate quality. In this process, a high-octane component – raw alkylate – is produced, which is, then, used in motor gasoline blending, whereas a light alkylate, being a basic aviation gasoline component, is obtained by its separation.

C_4 hydrocarbon olefin feed is mixed with isobutane and introduced into a reactor to mix with sulphuric acid (98.5%). This mixture goes from the reactor into a settler where acid is separated and circulated from the settler bottom back into the reactor.

The hydrocarbon phase mixture is introduced into the expansion vessel via the reactor (tube bundle), at a pressure drop, hence a large expansion and concurrent reactor section cooling occurs.

The expansion vessel consists of two parts. In the first part, a mixture of alkylate and iso-butane is separated and in the second part, mainly iso-butane, which is sent back into the reactor to provide necessary excess of iso-butane and to maintain the process optimum temperature (4-7 °C).

The expansion vessel is under over-pressure (higher than 1 bar) so the complete steam phase, mainly propane, butane, and iso-butane, is fed into the compressor absorber to introduce a part of the phase into the other part of the expansion vessel where iso-butane is employed as a cooling agent, whereas the remaining steam phase is fed via a cooler and a separator back to the gas concentration depropanizer to serve as the alkylation process feed.

Alkylate and iso-butane mixture from the first part of the expansion vessel is led, via a heat exchanger, to the washing system. First washing is performed by caustic, to remove residual acid and, then, by water to remove residual caustic. Then, the mixture is introduced into the column-debutanizer. Isobutane is separated on the top of the column and is partly sent, via the cooler and separator, back to the column as a reflux and partly returned to the process as a recycle with made-up isobutane from the storage. n-Butane, as a column-debutanizer side stream product, is discharged to the storage via the cooler and separator.

The column bottoms product is an alkylate that can be used in motor gasoline blending or can be separated in the redistillation column as light and heavy distillates.

All the above mentioned technological characteristics are shown in fig. 1.

Energy characteristics of the process

In a typical alkylation with sulfur acid, iso-butane and butane fractions, from the gas concentration unit I and II, are introduced into a reactor where exothermic reaction occurs.

High pressure steam (HpS) is used for main pump and compressor drive, through the high-pressure steam condensing turbines.

Medium pressure steam (MpS) is used to heat auxiliary column, through heaters, and to drive pumps and compressors, through (MpS) turbines.

Low pressure steam (LpS) is obtained by reduction of medium pressure steam (MpS) on the MpS turbines.

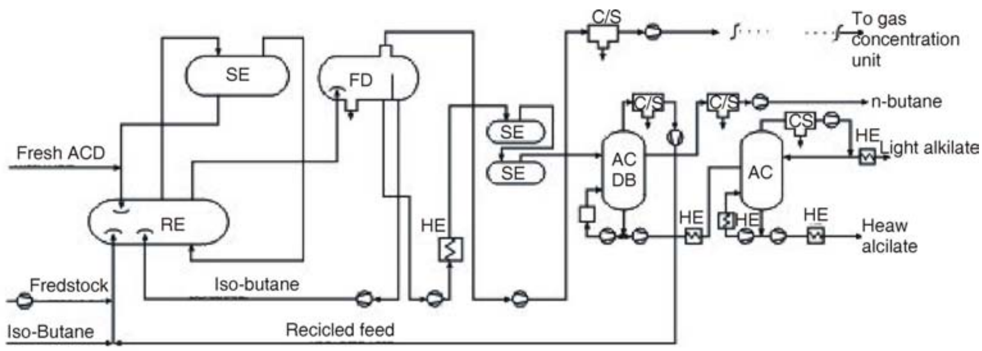

Figure 1. Technological characteristics of the alkylation unit
RE – reactor, SE – setler, FD – flash drum, DIB – deisobutanizer, AC – alkyliary column, HF – heat exchanger, CS – condenser separator

Total amount of steam is used for heating of tubes, equipment and other requirements.

Electric energy is used to drive pumps, fans and other equipment.

Main energy characteristics of the alkylation process are shown in fig. 2.

For the purpose of this process a block energy flow scheme is presented in fig. 3 and Senky's diagram for the energy balance in fig. 4. The values given for the energy consumption refer to the annual volume of production amounting to 59053 t.

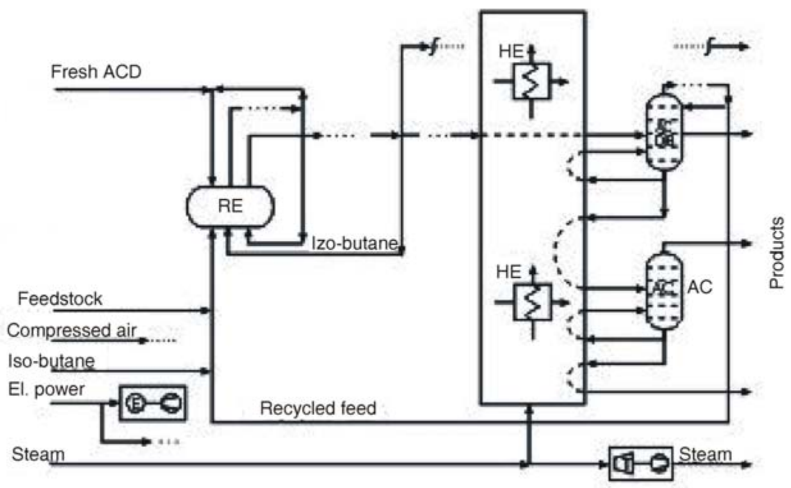

Figure 2. Energy characteristics of the alkylation unit
RE – reactor, AC – alkyliary column, DB – deisobutaner, HE – heat exchanger, E – engine, T – turbine

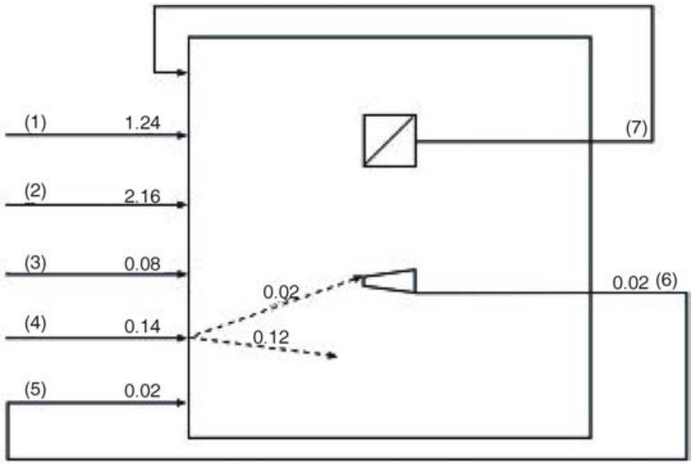

Figure 3. Block energy flow scheme of the alkylation unit
(1) – Cooling water [10^4 m^3/year], (2) – El. power [10^6 kWh/year], (3) – HP steam consumption [10^6 t/year], (4) – MP steam consumption [10^6 t/year], (5) – LP steam consumption [10^6 t/year], (6) – LP steam generation from back-presure steam turbine [10^6 t/year], (7) Heating the feedstock by means of product heat

High pressure steam consumption is 80000 t or 258 TJ. The consumption of medium pressure steam is 140000 t or 419 TJ. Own generation of low pressure steam, obtained by reduction on back-pressure turbines, is 20000 t or 55 TJ and it is used for own consumption.

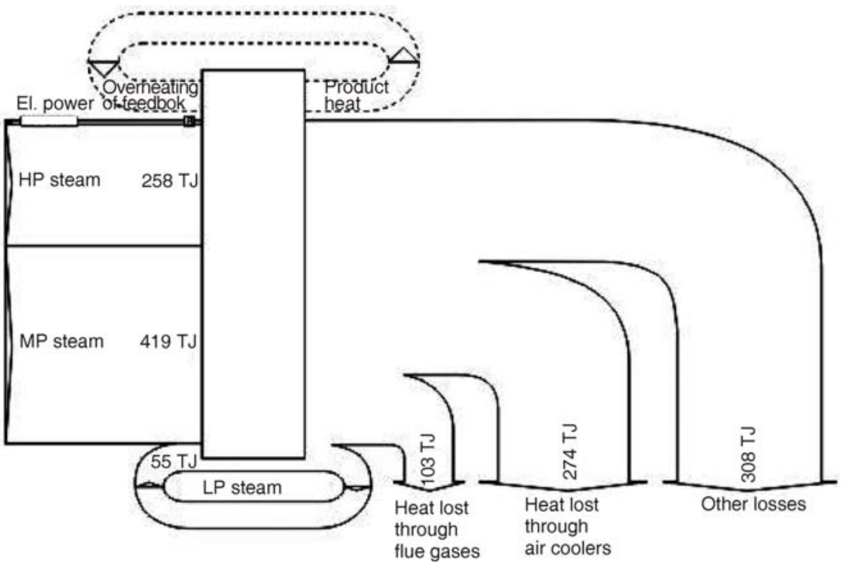

Figure 4. Senky's diagram for the energy balance of the alkylation unit

Determining the steam cost price

The cost prices of high, medium, and low pressure steam, which are used or produced on the alkylation unit, are shown in tabs. 1, 2, and 3. It should be emphasized that high and medium pressure steam is supplied from refinery power plant at 10.83 US$/t *i.e.* 9.66 US$/t while LpS is generated on the alkylation unit, by reduction of MpS and used for own consumption.

Table 1. Cost prices of high pressure steam (consumption)

Item No.	Elements for calculation	High pressure steam generation [HpS]		
		Annual quantity in t	Cost price US$/t	Total in US$
1	HpS supplied from refinery power plant	80000	10.83	866400

Table 2. Cost prices of medium pressure steam (consumption)

Item No.	Elements for calculation	Medium pressure steam generation [MpS]		
		Annual quantity in t	Cost price US$/t	Total in US$
1	MpS supplied from refinery power plant	120000	9.66	1159200

Table 3. Cost price of low pressure steam (production-consumption)

Item No.	Elements for calculation	LpS production [US$]			LpS for own consumption
		Annual quantity in t	Cost price US$/t	Total in US$	
1	MpS supplied from refinery power plant	20000	9.66	193200	193200
2	LpS by reduction of MpS	20000	9.66	193200	193200
3	Depreciation			35453	35453
4	Current and investment maintenance			4145	4145
5	Insurance premium for equipment			2763	2763
6	Total (2-5)	20000	11.78	235561	235561
7	Quantity in t			20000	20000
8	Cost price in US$/t			11.78	11.78

From tab. 3, it can be seen that the cost price of LpS steam which is generated by reduction of MpS, is very high (11.78 US$/t). It is higher than the cost price of medium pressure steam (9.66 US$/t) and HpS (10.83 US$/t).

This price of LpS is firstly effected by the price of MpS which is provided from the refinery power plant at the price of 9.66 US$/t and added by fixed costs *i. e.* depreciation, current, and investment maintenance, breakage and fire insurance of the equipment used to convert the MpS in LpS, at the total costs of 2.21 US$/t, so the final LpS price is 11.78 US$/t.

Energy efficiency of the process

Specific consumption of steam related to the amount of feedstock is:

$$\text{gross:} \frac{338\,\text{kg steam}}{\text{t of feedstock}} \quad \text{or} \quad 939.6\frac{\text{MJ}}{\text{t of feedstock}}$$

$$\text{net:} \quad 0\,\text{kg/t} \qquad 0\,\text{MJ/t}$$

Target standard of net energy consumption and specific gross and net energy consumption, in a typical alkylation unit, is outlined in tab. 4 while tab. 5 is the financial presentation of energy consumption and money savings which can be achieved by eliminating the differences between the target standard (average energy consumption of Western European refineries) and energy consumption of this refinery unit.

Table 4. Target standard of net energy consumption and specific energy consumption in a typical alkylation unit (quantity of energy per one tonne of feedstock)

Energy carriers	Target standard of net energy consumption		Specific energy consumption in the plant					
			Specific gross energy consumption			Specific net energy consumption		
			[kgt^{-1}]	[MJt^{-1}]		[kgt^{-1}]	[MJt^{-1}]	
	[MJt^{-1}]	[kWht^{-1}]	[kWht^{-1}]	Per unit	Total	[kWht^{-1}]	Per unit	Total
Heat carriers					12394.8			11455.2
– LpS	–	–	338	939.6		0	0	
– MpS	–	–	2370	7095.3		2370	7095.3	
– HpS	–	–	1354	4359.9		1354	4359.9	
Sources of heat	5866.8	–	–	–	12394.8	–	–	11455.2
Electric energy	133.2	37	39.0	140.4	140.4	39.0	140.4	140.4
Energy carriers	6000	–	–	–	12535.2	–	–	11595.6

Table 5. Financial presentation of energy consumption and money savings in a typical alkylation unit (in US$)

Specific gross energy consumption		
Energy carriers	Quantity of feedstock (light residue)	**US$**
Low pressure steam	59053 t	(939.6 MJ/t 0.0042374 US$/MJ) = 235117
Medium pressure steam	59053 t	(7095.3 MJ/t 0.0032308 US$/MJ) = 1 353701
High pressure steam	59053 t	(4359.9 MJt 0.003363 US$/MJ) = 865855
Sources of heat	59053 t	**(12394.8 MJ/t 0.0033536 US$/MJ) = 2 454673**
Electric energy	59053 t	(140.4 MJ/t 0.0167 US$/MJ) = 138460
Energy carriers	59053 t	**(12535.2 MJ/t 0.00350309 US$/MJ = 2 593133**
Specific net energy consumption		**US$/t**
Medium pressure steam		(7095.3 MJ/t 0.0032388 US$/MJ) = 22.980258
High pressure steam		(4359.9 MJ 0.003363 US$/MJ) = 14.662343
Sources of heat		**(11455.2 MJ/t 0.00328607 US$/MJ) = 37.642601**
Electric energy		(140.4 MJ/t 0.0167 US$/MJ) = 2.344680
Energy carriers		**(11595.6 MJ/t 0.00344849 US$/MJ) = 39.987281**
Sources of heat		
Own net energy consumption		(11455.2 MJ/t 0.00328607 US$/MJ) = 37.64
Target net energy consumption		(5866.8 MJ/t US$/MJ
Difference		**18.36**
Energy carriers		
Own net energy consumption		(11595.6 MJ/t 0.00344849 US$/MJ) = 39.99
Target net energy consumption		(6000 MJ/t 0.00344849 US$/MJ)= 20.69
Difference		**19.30**

The difference between gross and net energy consumption appears in case of LpS, by reason of own generation in the process.

Conclusions

If specific net energy consumption of a typical plant is compared with the target standard, the following conclusion can be drawn:

- Specific electric energy consumption is close to the target standard.
- Specific net consumption of process and thermal energy (steam) amounts to 11455.2 MJ/t thus exceeding the target standard (5866.8 MJ/t) by 95%.
- Total specific net energy consumption is 11596.6 MJ/t being 93% higher than the target standard (6000 MJ/t). Compared with the net energy target consumption, a typical plant has efficiency/inefficiency index of 193.

Increased consumption of process and thermal energy in a typical plant is caused by different factors, the most important being:

– non-economical utilization of high pressure steam for pump and compressor drive, by means of steam condensing turbines, and
– non-economical utilization of medium pressure steam for pump and compressor drive by means of steam turbines.

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Апстракт

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Оптимизација енергије у рафинеријама нафте: постројење за алкализацију

Представљен је могући начин за одређивање енергетске ефикасности, узимајући за пример рафинеријско постројење за алкилацију. Са енергетског аспекта, ефикасност и оптимизација постројења алкилације анализира се кроз цену водене паре високог, средњег и ниског притиска, и могуће уштеде које се могу реализовати елиминисањем разлика између циљног стандарда (средњи стандардни утрошак енергије у западноевропским рафинеријама) и специфичног утрошка енергије.

Потрошња паре високог притиска (ВиП) је 80000 t годишње или 258 TJ. Потрошња паре средњег притиска (СрП) је 140000 t годишње или 419 TJ. Сопствена производња паре ниског притиска(НиП), добијена редукцијом на турбинама са повратним притиском, је 20000 t годишње или 55 TJ, и користи се за сопствену потрошњу. Цена ВиП, коју обезбеђује рафинеријска енергана, је 10,83 US$/t, цена СрП, која се такође добија из енергетског постројења рафинерије, је 9,66 US$/t, а цена НиП, која се добија из јединице алкилације, је 11,78 US$/t.

Разматрајући могућности праћења и унапређења енергетске ефикасности и оптимизације, кроз циљни стандард нето потрошње и специфичну нето и бруто потрошњу енергије одабраног постројења, анализа показује да је индекс неефикасности 193%. Могуће уштеде, остварене елиминисањем разлика посматраних показатеља, су приближно 1,14 милиона US$ годишње. Уштеде се могу остварити и ефикаснијим технолошким, енергетским и организационим решењима. У раду је предложен метод за одређивање енергетске ефикасности.

Кључне речи: *процес алкилације, технолошке и енергетске карактеристике, енергетска оптимизација, уштеде трошкова, циљни стандард потрошње*

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